The Aerosol/Cloud/Ecosystems Mission (ACE)

Mark Schoeberl
NASA/GSFC

What is ACE?

ACE will help to answer emerging fundamental science questions associated with aerosols, clouds, air quality and global ocean ecosystems.

- Quantify aerosol-cloud interaction and assess the impact of aerosols on the hydrological cycle.
- Determine Ocean Carbon Cycling and other ocean biological processes.

Why two goals?

- Ocean biology measurements and Aerosols meet at the algorithm level
  - Accurate estimation of the aerosol contribution to the backscatter radiation are required to make precise ocean biosphere measurements.
  - Aerosol interference with ocean color measurements has been a major limitation in past missions
- But, there are common science problems between the two communities as well!
  - Fertilization of the ocean by dust; What is will happen in the future with climate change?
  - Aerosol formation by oceanic emitted DMS; How will ecosystem generation of aerosols affect the planetary energy budget?

Expected impacts

- ACE will narrow the uncertainty in aerosol-cloud-precipitation interaction and quantify the role of aerosols in climate change.
- ACE will measure the ocean ecosystem changes and precisely quantify ocean carbon uptake.
- ACE measurements will improve *air quality* forecasting by determining the height and type of aerosols being transported long distances.

NAS Decadal Survey Description of ACE

- Objective: "…reduce the uncertainty in climate forcing in aerosol-cloud interactions and ocean ecosystem CO_2 uptake" - Decadal Survey pg 4-4

- Mission and Payload: … LEO, sun-synchronous early-afternoon orbit. The orbit altitude of 500-650 km. The NAS mission consisted of four instruments:

  - A multi-beam cross-track dual wavelength lidar for measurement of cloud and aerosol heights and layer thickness;
  - A cross-track scanning cloud radar* with channels at 94 GHz and possibly 34 GHz for cloud droplet size, glaciation height, and cloud height;
  - A highly accurate multiangle - multiwavelength polarimeter to measure cloud and aerosol properties (This instrument, would have a cross-track and along-track swath with ~1 km pixel size.)
  - A multi-band cross-track visible/UV spectrometer with ~1 km pixel size, including Aqua MODIS, NPP VIIRS, and Aura OMI aerosol retrieval bands and *additional bands for ocean color and dissolved organic matter*."

* Doppler would be desirable too

ACE Science Objectives Extended

➢ ACE Extended – the ACOB mission

- NASA-sponsored workshops concluded that ACE should include more cloud measurement capabilities and assess the role of precipitation in aerosol-cloud interaction. This could be done by adding high and low frequency µ-wave radiometers to the potential payload.
  - The ACE SWG published a science White Paper that specifically addresses the rationale, requirements and resulting measurements associated with an extended version of ACE – the ACOB mission.
- Aerosol Climate and Ocean Biology (ACOB) mission is identical to ACE except for two µ-wave radiometers that strengthen the measurement of clouds and precipitation -- ACOB adds *significant* science.
  - The addition of the µ-wave radiometers broadens the ACE swath
  - Consistent with "Vital Skies" white paper recommendation that preceded the ACE white paper.
- Adding µ-wave radiometers will increase the cost *slightly*

Aerosol – Cloud Community Measurement Strategy

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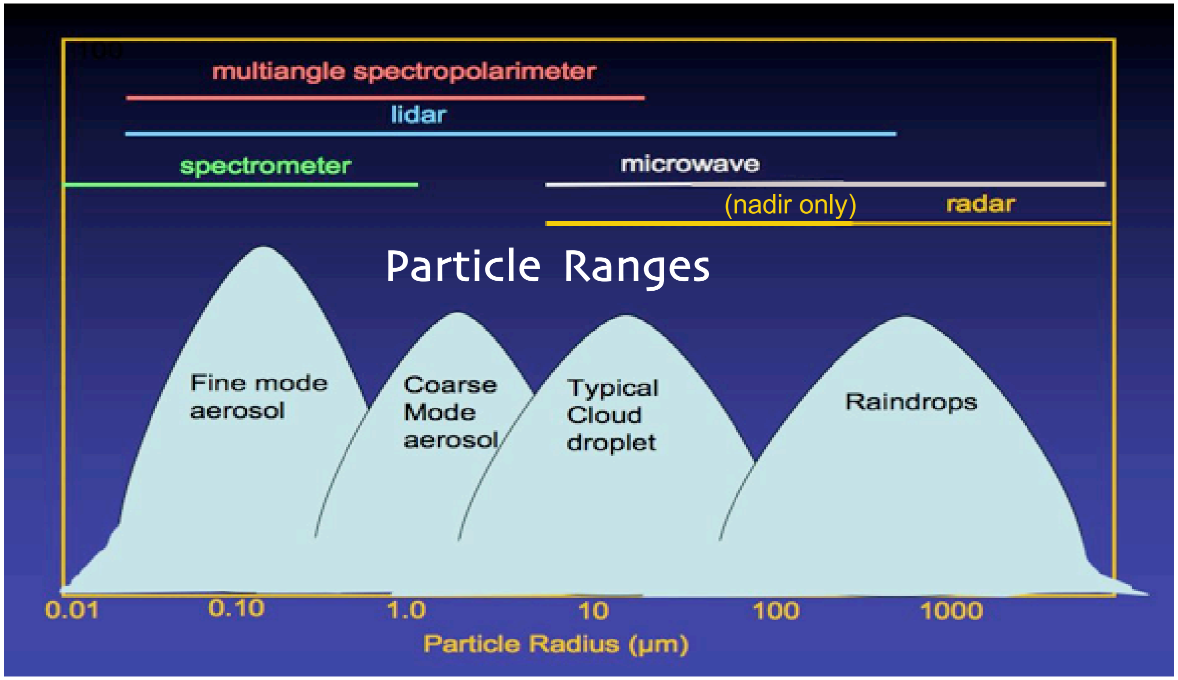

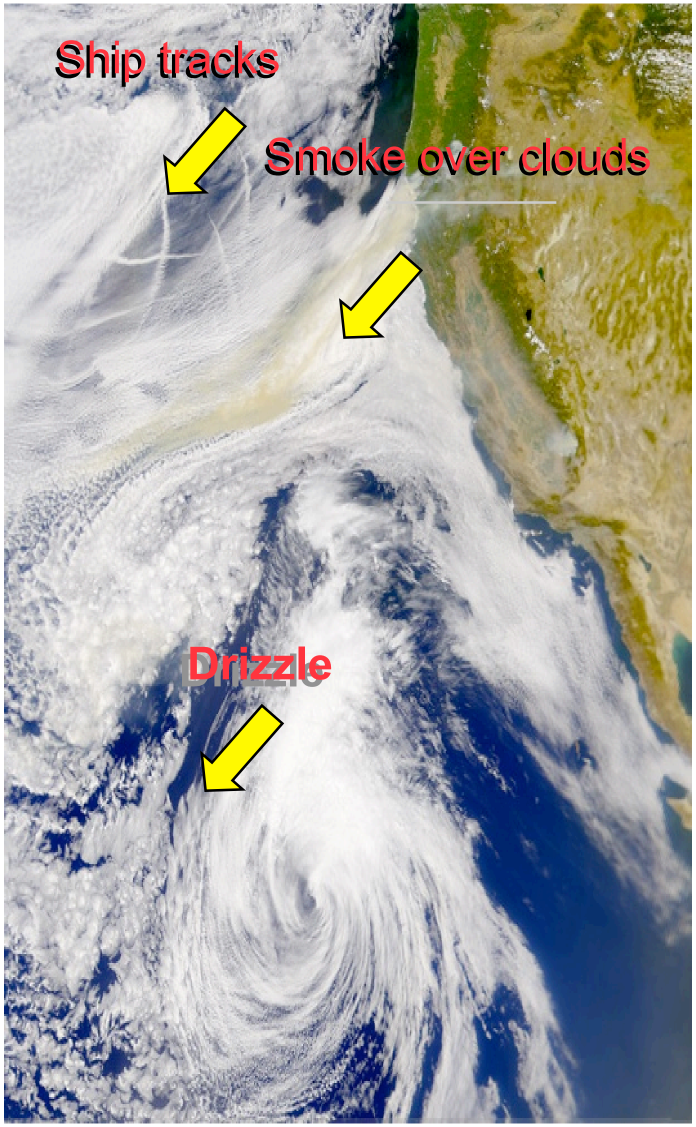

In order to understand the interaction between pollution, clouds and precipitation and to address air quality we need measurements that are sensitive to:

- particle distribution from fine mode to raindrops
- aerosol and cloud particle optical properties
- aerosol and cloud heights
- aerosol composition

Following the measurement suite pioneered by the A-Train, a *combination of active and remote multi-wavelength sensors* is needed.

Ocean Biology Research Goals

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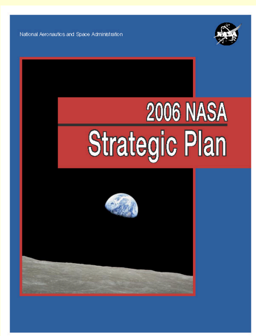
ACE Ocean Measurements Trace Directly to *Science Goals*

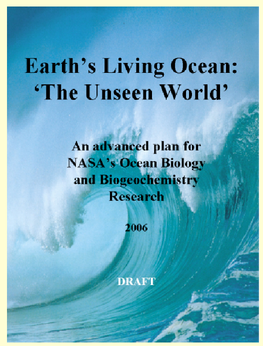
* Short UV for advanced atmospheric correction

NASA Strategic Plan



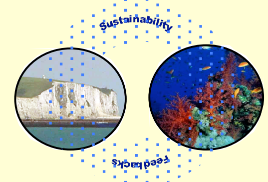
- Understand Earth system
- New observations to detect and predict change

Ocean Biology & Biogeochemistry Plan



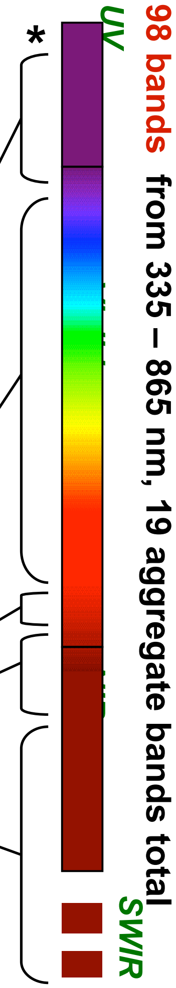
- Ecosystems & biodiversity
- Carbon/elemental cycles
- Habitats
- Hazards

Key Biochemistry & Biology Properties



- Dissolved carbon
- Phytoplankton pigments
- Functional groups
- Physiology
- Particle size
- Calcite
- Fluorescence
- Coastal biology
- Atmospheric corrections*

Ocean Radiometer



Research objectives for Earth Science → lead to → *Ocean biology and biogeochemistry questions* → lead to → *Key environmental parameters* → lead to → *Measurement requirements*

Air Quality STM

<table>
<tr><th>Category</th><th>Focused Questions</th><th>Approach</th><th>Measurement Requirements</th><th>Instrument Requirements</th><th>Platform Requirements</th></tr>
<tr><td rowspan="3">Air Quality</td><td>What are key region-specific local and distant sources of airborne dust, soot, sulfates, and organics?

What are the processes that govern long range aerosol transport and local deposition?</td><td rowspan="3">Retrieval of aerosol optical thickness and column particle microphysical properties by inverting radiance and polarization measurements
In order to:

(1) Characterize source locations, injection processes, and seasonal/annual fluctuations in emissions.

(2) Improve the modeling of processes affecting aerosol transport and deposition.

(3) Determine aerosol deposition rates to the surface by type and source.</td><td>Global distribution of column optical thickness, effective radius and variance, refractive index, type, number density, and single-scattering albedo of bimodal aerosol population using polarization and radiance measurements.</td><td>Polarimeter
- Swath ~2000 km
- At least 3 km horizontal resolution at nadir
- Narrow-band photopolarimetric measurements including:
o Several intensity +polarization channels in the 400-2200 nm spectral range
o Channels to detect and correct for thin cirrus.
o Channels to estimate total column water vapor.
o Polarization SWIR channels for retrievals over land
o 3% radiometric accuracy..
o 0.1% polarization accuracy along the ground track 0.5% polarization accuracy for global coverage</td><td rowspan="3">Sun synchronous with crossing time between 10 am and 2 pm</td></tr>
<tr><td rowspan="2">What are the trends in anthropogenic and natural contributions to aerosol pollution near the surface?</td><td rowspan="2">Spatially sampled distribution of vertically resolved (to within 20 m) optical depth, effective radius, effective variance, refractive index, type, number density, and single-scattering albedo for two modes of the aerosol population over as much of the swath as possible</td><td>Lidar
- Vertical resolution of at least 100 m.
- Dual wavelength - 532 & 1064 nm
- Dual polarization to separate particle types
- HSRL or other technique to obtain direct determination of extinction
Better SNR than Calipso
Cross Track Lidar – measurements extended to 175 km on either side of nadir</td></tr>
<tr><td>Polarimeter as above and…
Rayleigh scattering + polarization estimates for aerosol altitude. Requires UV channel on polarimeter</td></tr>
</table>

Ocean Biology STM

Category	Focused Questions	Approach	Measurement Requirements	Instrument Requirements	Platform Requirements
Ocean Biology	• How do aerosols deposited on the ocean surface influence nutrient levels and stressors for ecosystems? • How do ocean biological processes influence aerosol and cloud distributions? • What are the standing stocks, transformation rates, and fates of marine organic carbon pools as well as inorganic particles. • How do climate and habitat changes influence the productivity and elemental cycles of the global oceans?	• Estimate atmospheric aerosol (dust) deposition to the ocean.Characterize the responses of marine ecosystem stocks and rates to aerosol inputs. • Compare historical atmospheric correction algorithms with results for a fully-resolved aerosol load and distribution. • Define environmental factors regulating the release of important atmospheric aerosols (e.g. DMS) and quantify flux and spatial distribution • Quantify carbon-standing stocks within global ocean ecosystems and their uncertainties. • Quantify ocean primary productivity and loss pathways to assess carbon export. • Estimate elemental fluxes from terrestrial to ocean margin to open ocean environments. • Characterize elemental fluxes between the upper water column and deeper ocean layers (including the near-shore sedimentary layer) • Distinguish key particle types and phytoplankton functional groups. • Determine how optically complex near-shore waters influence uncertainties in remote sensing data products. • Test and improve satellite-derived products and processes through comparison with field sea-truth data and modeling.	Measurement of water leaving radiances allowing the separation of absorbing and scattering constituents in the near ultraviolet and visible bands Measurement of water leaving radiances red and near-infrared for calculation of fluorescence line heights. . Measurement of total radiances in UV, NIR, and SWIR for atmospheric corrections. Measurement of cloud radiances to account for instrumental stray light	**Multi-wavelength radiometer** ozone column measurements to 5% Measurements from 345 nm to 800 nm with 5 nm resolution. 1000 to 1500 SNR for UV through visible for 20 nm aggregate bands, 180 to 750 SNR for 10 to 40 nm aggregate bands in the NIR and SWIR 0.5% radiometric accuracy 0.1% relative radiometric stability 58.3^0 cross track scanning +20 to -20 degree sensor tilt for glint avoidance	Orbit at 650 km for 2 day coverage Sun synchronous 10:30AM to 2:30 PM crossing time .
			Measurement of aerosol heights and optical thickness to identify and correct for absorbing aerosols in the calculation of water-leaving radiances	**Lidar** **(as with Air Quality)**	
			Measurements of aerosol heights over a wide swath to identify and correct for absorbing aerosols in the calculation of water-leaving radiances Measurement of oceanic polarized return to improve typing of oceanic particles.	**Polarimeter** **(as with Air Quality)**	

Aerosol/Clouds STM

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<table>
<tr><th>Category</th><th>Focused Questions</th><th>Approach</th><th colspan="3">Measurement Requirements</th><th>Instrument Requirements</th><th>Platform</th></tr>
<tr>
<td rowspan="13">Aerosols Clouds and Climate</td>
<td rowspan="3">Aerosols, Clouds and Radiation

How do aerosols affect the Earth's radiation budget (ERB)?

How do aerosol affect the radiative properties of clouds (also see section below), and how do these effects vary with aerosol properties?

How do the above effects partition between natural and anthropogenic aerosols?</td>
<td rowspan="3">Partitioning of direct radiative forcing by aerosol amount, type, and source.

Quantification of aerosol and cloud effects on surface heating rate and the vertical heating rate profile.

Quantification of cloud suppression by absorbing aerosols.

Quantification of the direct effect of anthropogenic aerosols and cloud suppression by absorbing aerosols.</td>
<td rowspan="13">The desired cloud and aerosol properties can not be obtained from a single instrument, but will require carefully collocated measurements from a variety of instruments.

"two swath" approach where vertically resolved measurements are provided on a relatively narrow-swath and imaging polarimeter data and scanning passive microwave data are used to provide additional context over a much larger domain.

Retrievals which combine observations from all instruments will be used in narrow-swath region.

Wide-swath/imager observations are then combined with retrievals from the narrow-region to improve retrievals over imager-only approaches for the full domain.

For mid-trop clouds aerosol sources are less likely to be local and swath coverage becomes more important.

Vertically integrated column ice water path from microwave radiometer (which does include some information content on the vertical distribution of ice, though much less than that provided by cloud radar and lidar) is an important addition.</td>
<td rowspan="3">Aerosols</td>
<td>Horizontal / Imagery-based aerosol properties and heights
- Horizontal resolution 100 m (50 m or better desired).
- Total column optical depth to 0.05 or 10%, whichever is larger.
- Aerosol properties retrieval requirements, as per aerosol section.
- Measurement of vertically resolved (to within 0.5 km) of aerosol height over a broad swath</td>
<td>Polarimeter
As above plus sufficient angles and wavelengths to provide :
- stereo cloud-top-heights
- stereo cloud-top-winds
- cloud particle size
- cloud-particle phase and limited ice crystal habit characterization.
- long slant paths through the atmosphere (increasing sensitivity for thin clouds)
Desired: Polarization and angular capability for "rainbow" retrieval of particle size for water clouds</td>
<td>Sun synchronous with crossing time between 10 am and 2 pm</td>
</tr>
<tr>
<td>Vertical / Lidar resolved aerosol properties
- Vertical resolution of 100 m or better.
- Horizontal resolution of 500 m or better.
- Aerosol properties retrieval requirements, as per aerosol section.</td>
<td>Lidar
As above</td>
<td>Orbit altitude between 450 and 650 km</td>
</tr>
<tr>
<td>Broadband longwave and shortwave radiance measurements with accuracy at least as good as the current CERES instrument.</td>
<td>Broadband ERB
Measurement broadband Earth-reflected solar shortwave (0.3 - 5.0 micrometer) and Earth-emitted long wave (5.0 - greater than 100 micrometer) radiances as well as emitted longwave radiances in the 8 - 12 micrometer water vapor window over geographical footprints 10 kilometers at the nadir.</td>
<td>Need to co-fly with ERB instrument s or include ERB sensor on payload</td>
</tr>
<tr>
<td rowspan="10">Cloud-Aerosol Processes

How do different types of aerosols affect cloud cover, cloud phase, cloud water content and cloud particle size for water clouds, mixed phase clouds and ice clouds? How do these factors affect cloud albedo?

Are clouds fundamentally brighter in conditions of heavy aerosol?

Do aerosols exert a significant effect on the environmental controls on cloud life cycle processes?

How do aerosols affect warm and cold precipitation processes?

How do different cloud types influence aerosol number and mass concentration, vertical profile and size distribution?

Do changing aerosols significantly control the initiation of precipitation?

What factors establish the precipitation efficiency of weather systems, and is this efficiency influenced by aerosols?</td>
<td rowspan="10">Quantification of changes in cloud properties and brightness (IDE) due to natural and anthropogenic aerosols and isolating these effects from meteorology, large-scale forcing, and other factors.

Quantification of changes in aerosol properties in the presence of clouds

Determination of precipitation rates within clouds.

Differentiation between precipitating cloud condensate and non-precipitating condensate and between types of precipitating condensate

Determine cloud macrophysical properties (horizontal coverage, vertical extent and cloud-top-height) and microphysical properties (total column optical depth, vertically resolved cloud phase, water content and particle size) in both clean and aerosol loaded environments.

Determine aerosol optical properties (total column optical depth, column average single-scattering albedo, vertically resolved extinction, as well as some measure of column-effective particle size and sphericity in clear-skies including the near-vicinity of clouds, especially broken cumulus.

Aggregate cloud properties as a function of aerosol optical properties, as well as ancillary data on the atmospheric dynamical state, likely aerosol type, distance of aerosol from source of origin, etc. to determine if there are significant changes in clouds properties with these other variables.

Cirrus clouds with optical depths greater than 0.05 must be identified and incorporated into combined aerosol-cloud retrievals.</td>
<td rowspan="4">B'ndary Layer Clouds</td>
<td rowspan="4">Horizontal / Imager-based cloud properties
- Coverage (cloud detection) with horizontal resolution of at least 100 m (50 m or better desired). Failed detection rate less than 1% and a false detection rate less than 4%.
- Total column optical depth to better than 50% for clouds with a total optical depth greater than 1.
- Column effective particle radius to 20% or better for single phase clouds.
- Cloud-top-height to 50m or better with uncertainty of less than 50 m.
- Effective visible-wavelength cloud-phase with low probablilty of false determination (less than 20%).

Measurement of aerosol properties as above
Vertical / Radar resolved cloud properties
- Vertical resolution of 120 m minimum (30 to 60 m desired).
- Horizontal footprint / field of view 500 m or better
- Ice/Liquid water content to 50% or better for clouds single-phase clouds.
- Cloud particle size to 20% or better for single-phase clouds.</td>
<td>Thermal IR Cloud Sensor
- Capability to estimate cloud height to ~1 km
- Compatibility with VIIRS and current EOS sensors IR bands
- wavelengths: 3.7, 8.5, 11, 12, several CO_2 bands near 13 um.
- Calibration to at least 0.5K.</td>
<td>none</td>
</tr>
<tr>
<td>Polarimeter
As above</td>
<td>Sun synchronous with crossing time between 10 am and 2 pm</td>
</tr>
<tr>
<td>Backscatter Lidar
As above</td>
<td rowspan="2">Orbit altitude near 450 km recommended.</td>
</tr>
<tr>
<td>Cloud Radar
- vertical resolution: 120 m (or better)
- horizontal footprint: 1/2 km
- Sensitivity of better than -30 dBZe (-40 dBZe desired)
- Dual frequency (94&34GHZ)
Scanning or Multibeam capability recommended</td>
</tr>
<tr>
<td rowspan="6">Mid-trop. clouds and convective clouds</td>
<td rowspan="6">Horizontal / Imager-based cloud properties
- Coverage (cloud detection) with horizontal resolution of at least 500 m.
- Failed detection rate less than 1% and a false detection rate less than 4%.
- Cloud Properties retrievals, as per boundary layer clouds
Horizontal / high frequency scanning radiometer for ice cloud properties
- Horizontal resolution: a few km
- Ice water path (IWP) to 50%.
Vertical / Radar resolved cloud properties
- Vertical resolution of 240 m (minimum).
- Horizontal resolution: 1 to 2 km.
- Cloud Properties retrievals, as per boundary layer clouds.
Horizontal / Imagery-based aerosol properties
- Horizontal resolution ~ few km.
- Aerosol properties retrieval requirements, as per aerosol section.
Vertical / Lidar resolved aerosol properties
- Vertical resolution of 240 m or better.
- Horizontal resolution of 500 m or better.
- Aerosol properties retrieval requirements, as per aerosol section.
Swath width
- Passive Instruments: Minimum 400 km
Active instruments: Scanning or multiple beams are not indispensable but strongly desire</td>
<td>Polarimeter
As above but 250-500m horizontal resolution</td>
<td rowspan="2">Sun synchronous with crossing time between 10 am and 2 pm</td>
</tr>
<tr>
<td>Backscatter Lidar
As above</td>
</tr>
<tr>
<td>Cloud Radar
as above
- vertical resolution: 240 m (or better)
horizontal footprint: 1 to 2 km</td>
<td rowspan="4">Orbit altitude between 450 and 650 km</td>
</tr>
<tr>
<td>Thermal IR Cloud Sensor
As above</td>
</tr>
<tr>
<td>High Frequency μ-wave
Radiometer for IWC and cloud ice properties in combination with radar. Conically scanning ~53deg incidence angle: 800-183 GHz.

Footprint ~10 km</td>
</tr>
<tr>
<td>Low Frequency μ-wave
Wide swath microwave radiometer for bulk water contents and precipitation also to be matched to radar

Conically scanning ~53deg incidence angle: 10.65-183 GHz

Footprint: ~10 km</td>
</tr>
</table>

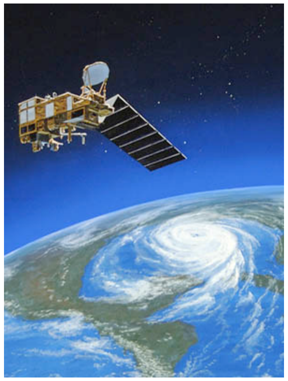
Cloud/Radiation STM

Category	Focused Questions	Approach	Measurement Requirements	Instrument Requirements	Platform Requirements
Clouds and Radiation	How are atmospheric and surface heating or cooling distributed and what cloud properties govern this distribution? How do these radaitive effects vary on intra-seasonal and interannual to decadal time-scales? What cloud properties that have the most pronounced influence on the Earth albedo? Specifically: • Has the vertical distribution of cloud liquid or ice water content changed since the launch of the EOS CloudSat and Calipso missions? • How does the vertical distribution of cloud liquid and ice water content respond to significant modes of climate variability?	Quantify vertical cloud microphysical properties compatible with (but superior to) the A-train sensors through radar and lidar observations..	Determine cloud vertical structure with 120 m (or better) resolution and estimate cloud properties of water, ice and precipitation at this resolution. Retrievals must be at least as good as can be achieved with current A-train sensors.	**Lidar** As above **Polarimeter** As above **Multiwavelength radiometer** As above **Cloud radar** As above **High Frequency µ-wave** As abovet **Low Frequency µ-wave** As above **Thermal IR Cloud Sensor** As above	Orbit at 650 km for 2 day coverage Sun synchronous 10:30AM to 2:30 PM crossing time
	Is the Earth radiation budget and atmospheric heating changing in response to changes in the vertical structure of clouds?	Estimate outgoing top of atmosphere longwave and shortwave fluxes collocated with cloud property retrievals in order to determine the influence of microphysics on the radiation budget of clouds. Combine these data with estimates of atmospheric heating rates using cloud properties retrievals (described in connection with question CR-1)	Broadband longwave and shortwave radiance measurements with accuracy at least as good as the current CERES instrument.)	**Broadband ERB** As above	Need to co-fly with ERB instrument or have frequent crossing times or include ERB sensor on payload

STM-based ACE/ACOB Instrument Requirement

Science Requirement	Instrument Type	Mission
Characterization of aerosols types and modal distribution over a broad swath	Multi-angle polarimeter	ACE/ACOB
Altitude of and properties of aerosols/clouds	Backscatter multi-beam /HSR lidar (active)	ACE/ACOB
Cloud microphysics within the cloud	Dual frequency cloud radar (active)	ACE/ACOB
Ocean color	Multi-band spectroradiometer	ACE/ACOB
Cloud height in the IR	IR stereo sensor*	ACE/ACOB
Cloud particle type and ice water path over a broad swath	High frequency μ-wave radiometer*	ACOB
Precipitation and liquid water path over a broad swath	Low frequency μ-wave radiometer*	ACOB

What is planned for the 2015 time frame?



- NPOESS (800km):
  - VIIRS & CERES(?) & CrIS (IR)
  - No vertical profiling information for clouds or aerosols
  - VIIRS severely limited in aerosol measurement capability
  - Following Nun-McCurdy descope: No multi-angle polarimetric imaging for reducing aerosol uncertainties
- EarthCARE (450km):
  - CPR (94 GHz, JAXA), HSRL, BBR (2 channels, 3 views),
  - Multi-spectral imager (7 channel 0.6-12 μ, 150 km swath)
  - CPR has Doppler capability, first space HSRL
  - No polarimeter, imager is limited

NASA Studies of ACE

- GSFC led study of NAS mission
  - Produced a ST Matrix and white paper
  - Considered NAS instruments
  - HQ required a 2 spacecraft solution
    - Partly because of the size of the MBL
    - Partly because of the HQ view - smaller spacecraft are better to manage
  - Added some additional instruments
  - Cost roughly 2x the Academy number
    - Probably could save >$200M by scrubbing the payload and bus
    - Iteration on instrument requirements would probably bring costs down as well
    - Dual launch – requires a $50M DPAF one time charge
- JPL led study of ACE
  - No science traceability matrix
  - Considered a more advanced radar that included Doppler capability
    - No Radiometers or IR instruments
  - Lowered the orbit to 480 km (vs 645 km) which improves capabilities of most of the sensors
    - The Goddard study used 645 km because that was the design altitude of ORCA - ORCA has since relaxed this requirement
  - Considered single spacecraft solution (Good!) on a Delta II (no more of those, sorry)
  - Consider HSRL rather than Multi-beam
  - Suggested more opportunities for international partnering
  - Costs ~1.5x the Academy number

GSFC Study Candidate Instruments

- In no way should this be considered pre-selection
- Instruments were used for power, weight, size and data rate design envelopes
  - MSPI power and weight, PACS data rate
  - Multi-beam used instead of HSRL because it defined the volume envelope – HSRL is a lot smaller
  - Radar/radiometer platform not completely designed – Cloudsat used as a bogy

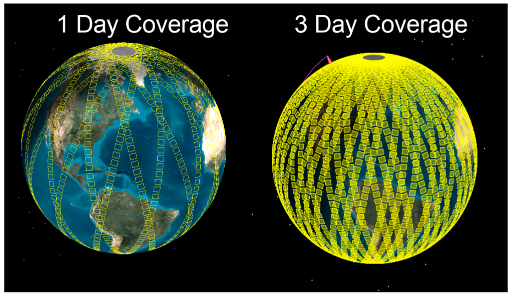
Multi-Beam Lidar

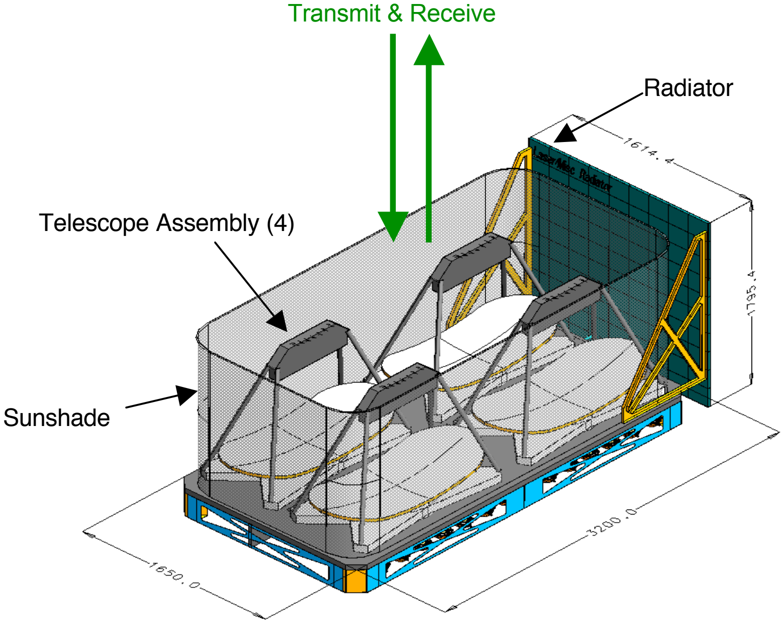
Continue profile observations after CALIPSO.

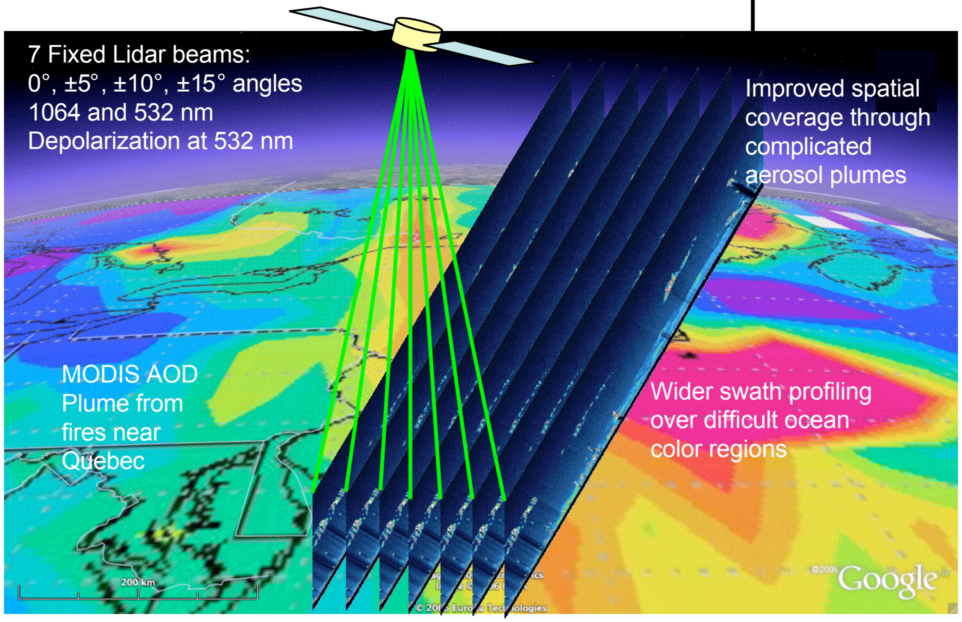
Wider swath for better global coverage:

- multiple beams increase number of statistical-based mission observations
- enables better aerosol emission/source identification
- improved ability to track plumes during long-range transport
- combined lidar and imager observations (e.g. ocean biology)

Beam spacing fine enough to resolve aerosol structure across most plumes, near sources, and for downwind advection





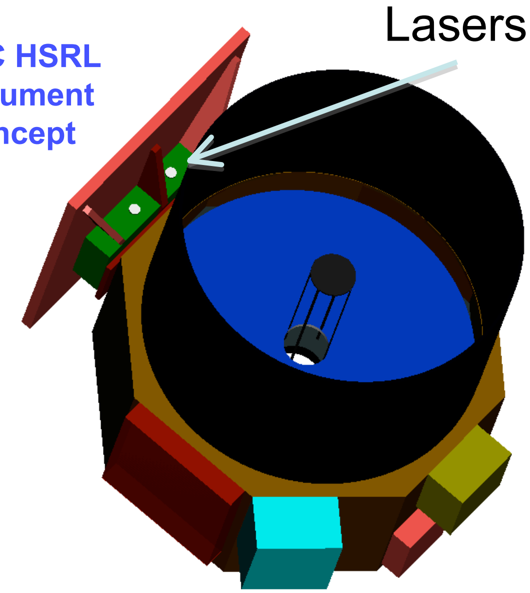


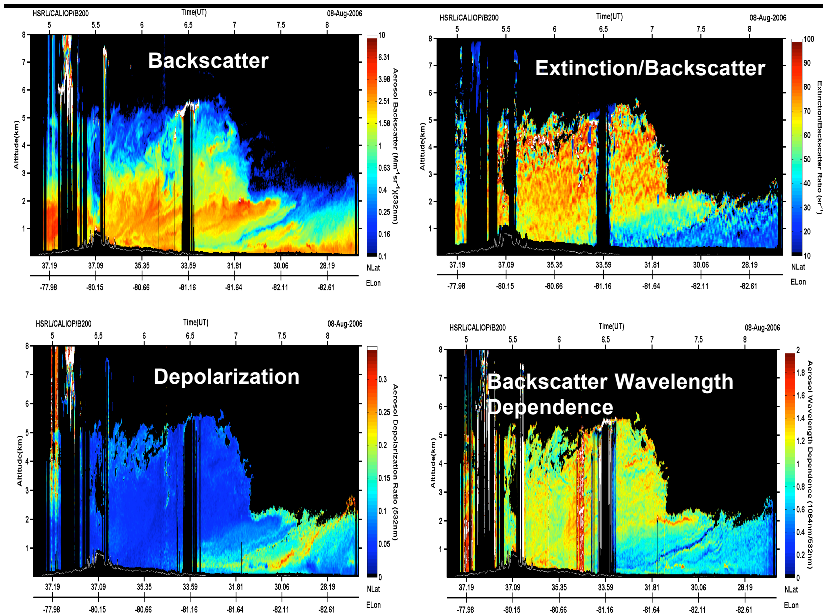
Multiwavelength High Spectral Resolution Lidar (HSRL)

Goddard Space Flight Center

- Multiwavelength HSRL
  - Backscatter at 3 wavelengths (3 β) : 355, 532, 1064 nm
  - Extinction at 2 wavelengths (2 α) : 355, 532 nm
  - Depolarization at 355, 532, and 1064 (dust and contrails/cirrus applications)
- Retrieved, layer-resolved, aerosol microphysical and macrophysical parameters
  - Effective and mean particle radius (errors < 30-50%)
  - Concentration (volume, surface) (errors < 50%)
  - Complex index of refraction (real:±0.05 to 0.1; imaginary (<50% if > 0.01)
  - Single scatter albedo (SSA) (±0.05)

LaRC HSRL Instrument Concept





Data from LaRC Airborne HSRL

Aerosol Lidar Information Content

Backscatter Lidar

- Aerosol layer heights
- Qualitative vertical distribution (backscatter profile)
- Qualitative aerosol typing information
- Extinction profile derived from backscatter

Backscatter Lidar + Passive

- Extinction profile using column constraint
- Fine-coarse mode fraction vs. altitude

Multiwavelength HSRL

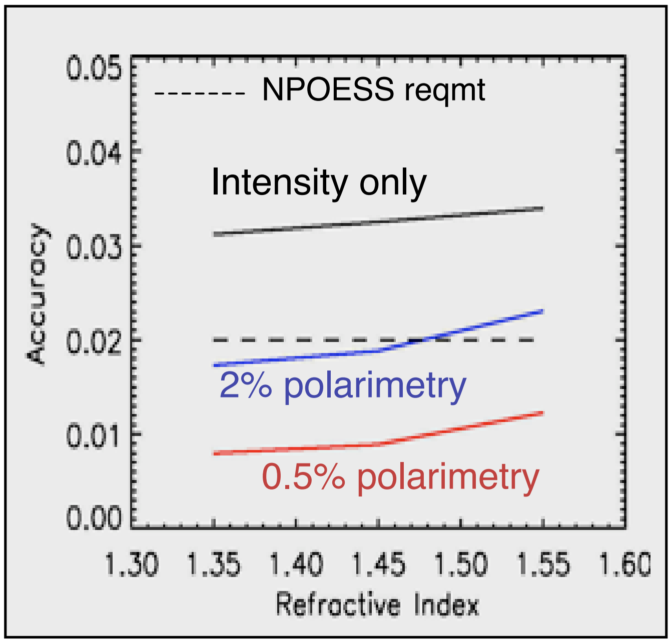
- Extinction profile
- Complex refractive index vs. altitude
- Aerosol size vs. altitude
- Single scatter albedo vs. altitude
- Concentration vs. altitude

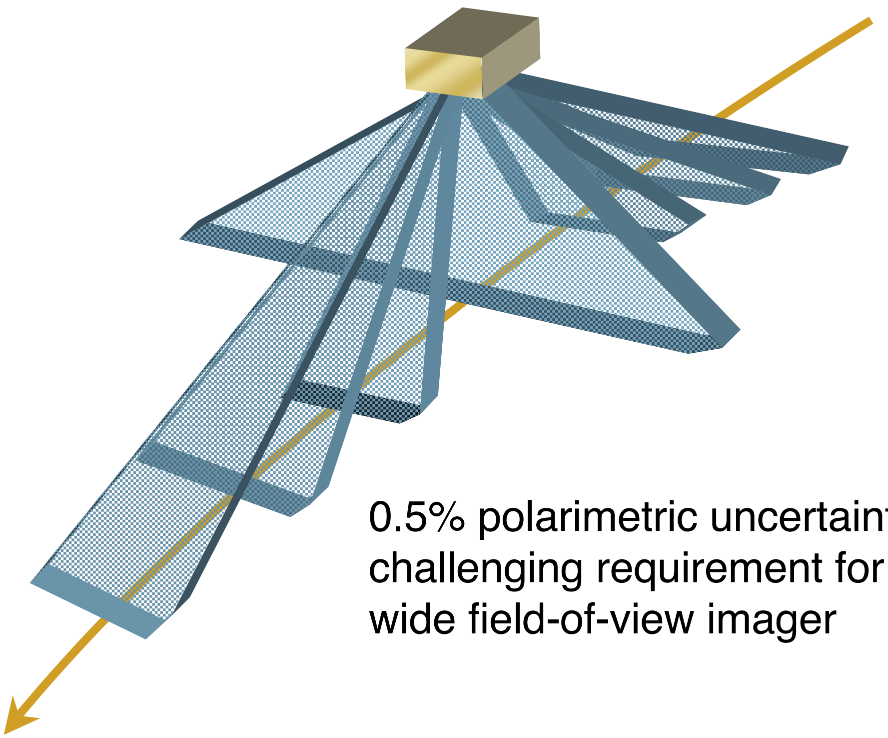
MSPI - Advanced MISR Instrument

Multiple cameras with extended spectral range, polarimetry, and wider swath

Synergistic use of multiple techniques reduces retrieval indeterminacies

- multiangle: particle size, shape, retrievals over bright regions (deserts, cities)
- multispectral: particle size (visible and SWIR), absorption and height (near-UV)
  - nominal bands: 380, 412, 446, 558, 650, 865, 1375, 1610, 2130 nm
- polarimetric: size-resolved refractive index and size distribution width
  - nominal bands: 650, 1610 nm





0.5% polarimetric uncertainty is a challenging requirement for a wide field-of-view imager

Ocean Color Instrument (ORCA)

Goddard Space Flight Center

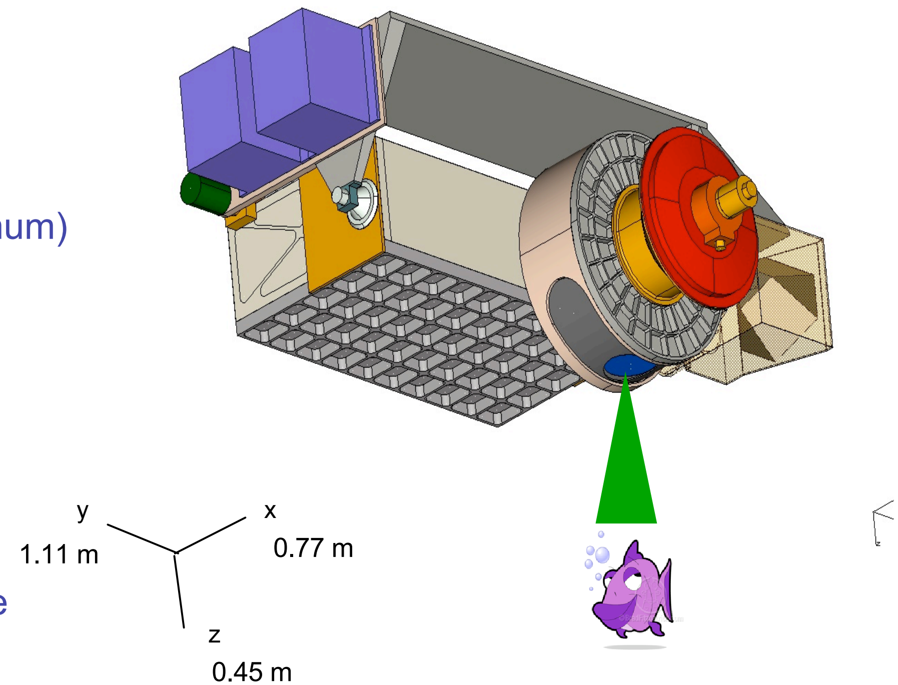
ORCA is a spectroradiometer designed for ocean remote sensing

Instrument Concept

- Scanning Spectrograph
  - +/-58.3 deg. cross-track scan
  - 2500 km swath
- 98 bands from 335 – 865 nm
- 19 aggregate bands total for ocean science (minimum)

Spectral Range	SNR Specs
Near UV (335-400nm)	750-1500
Visible (400-700nm)	1000-1500
NIR (700-1640 nm)	750-180

- Other bands can be used for aerosol/cloud science



- Two day global coverage from 650km orbit
- Data collected to 75 deg. latitude of sub-solar point
- ¬ Monthly lunar calibration maneuver (dark side)
- ¬ Daily solar calibration (pole)
- ¬ Spectral calibration (solar-based)
- ¬ Sun glint avoidance (sensor tilting)
- Five year design life

All instrument technologies are TRL ≥ 6

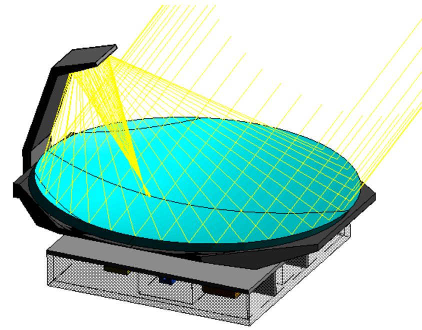
Dual Frequency Cloud Radar

Products:

- Cloud top height
- Microphysical profile information
- Particle phase/glaciation height
- Ice Water Content and Cloud Water Content
- Precipitation detection

Scientifically Desirable:

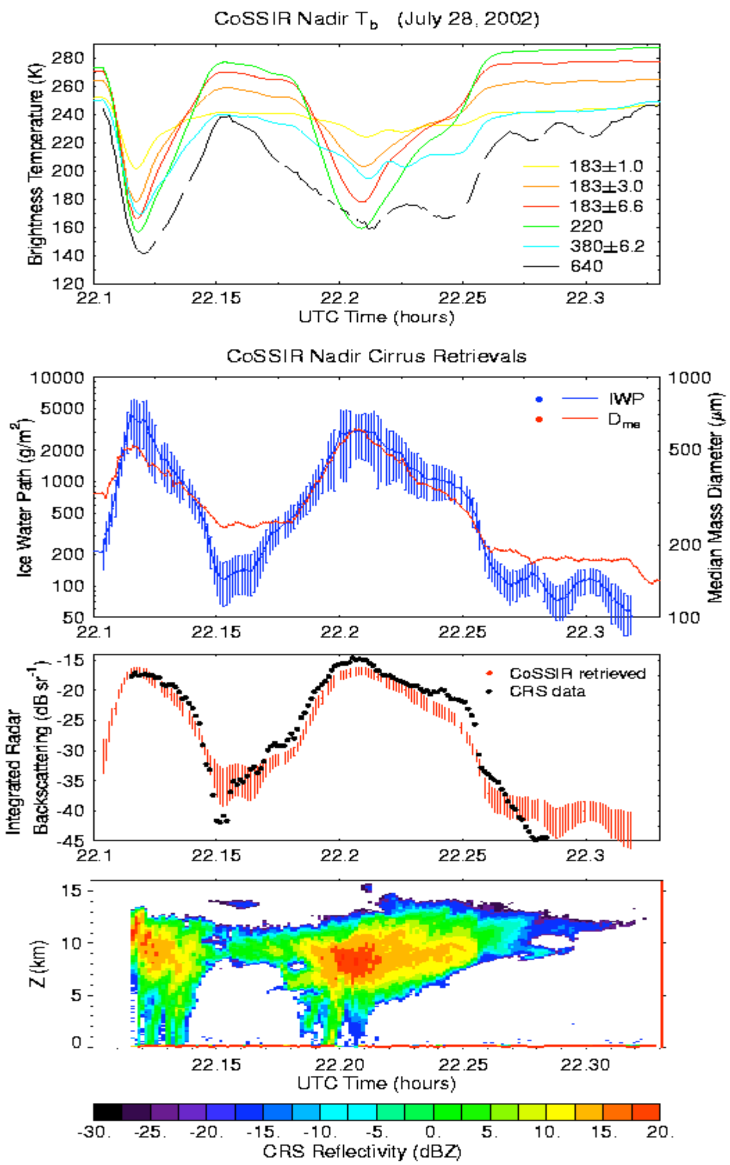
- Swath
  - Even a narrow swath will be difficult because of the narrow back scattering phase function
  - It is unlikely that the cloud radar can point more than 10º off nadir
- More sensitivity to precipitation
- Sensitivity to low clouds (aerosols probably have more effect on them)
- Doppler capability



Radar Measurement	Cloud/precip structure & microphysics	
Wavelength	94GHz (CloudSat, EarthCare)	94GHz and 34 GHz
Cloud top height (± 1 km)	✔	✔
Glaciation level	✔	✔
Precipitation		✔
Droplet distribution to 300µ		✔
Cloud water content profile	✔	✔

High Frequency μ-wave Cloud Radiometer

Goddard
Space
Flight Center



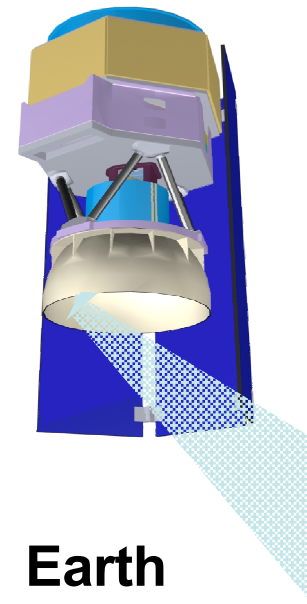
Submillimeter/Millimeter (SM4) Radiometer

- Conical Scanning Imager with 1600 km swath
- 10-km spatial resolution => 0.36∞ pencil beam
- 6 Receivers > 12 Channels
- Vertical + Dual Polarization at 643 GHz

{183V, 325V, 448V, 643 V&H, and 874V GHz}

- Three-point calibration (hot, cold, space cold)

- Heritage: MLS, CoSSIR, HERSHEL, MIRO



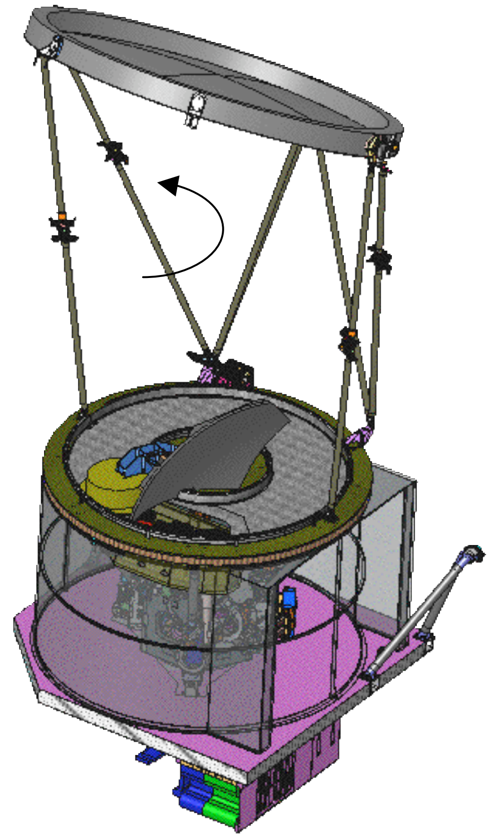
Low Frequency μ-wave Radiometer (GMI)

GPM Microwave Imager (GMI)
Key Products

- Rain rates from ~0.3 to 110 mm/hr
- Increased sensitivity to light rain over land and falling snow

ACOB-B would be a GPM daughter satellite

Ball Aerospace and Technology Corporation (BATC) is developing GMI

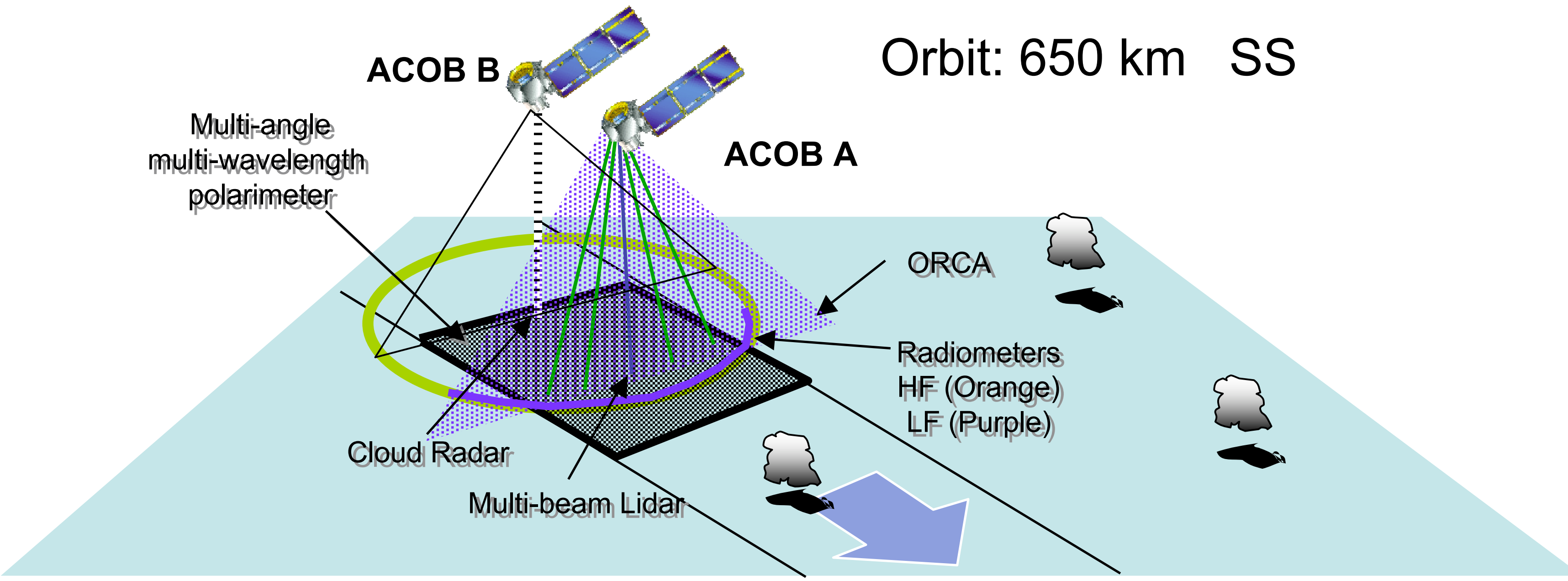


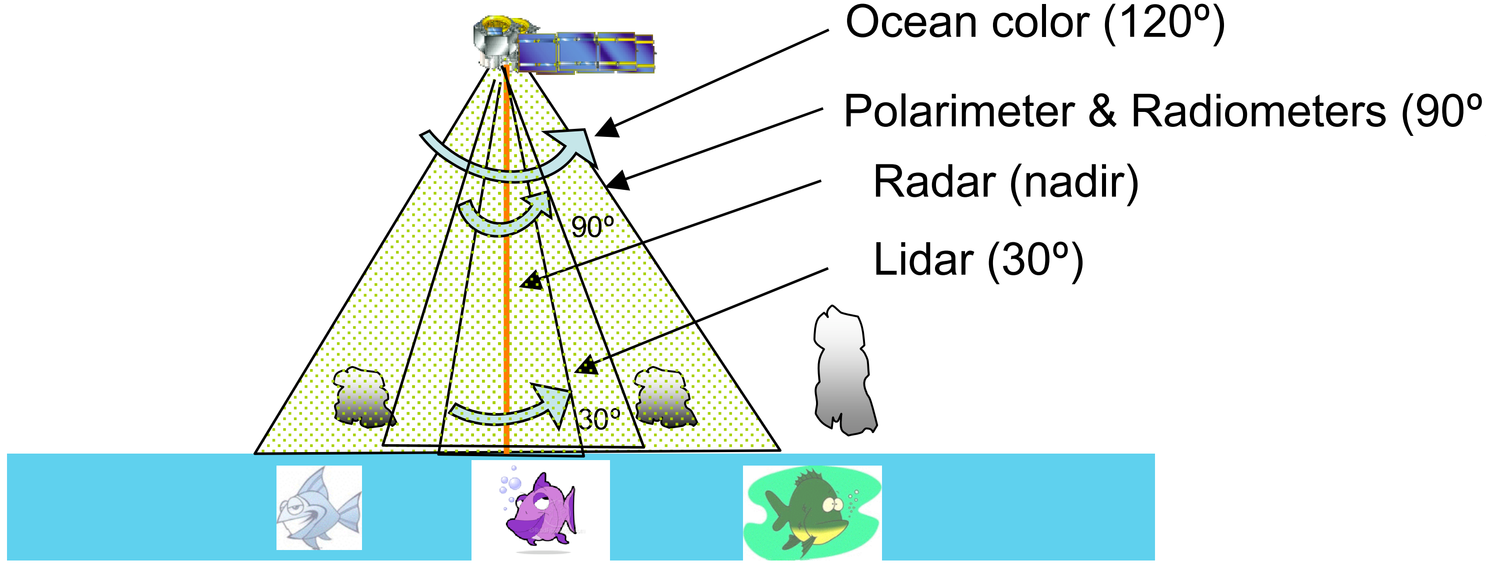
GMI Key Parameters

Mass (with margin):~150 kg
Power:~125 W
Data Rate:~30 kbps
Antenna Diameter:~1.2 m
Channel Set:
10.65 GHz, H & V Pol
18.7 GHz, H & V Pol
23.8 GHz, V Pol
36.5 GHz, H & V Pol
89.0 GHz, H & V Pol
166 GHz, H & V Pol,
183±3 GHz, V (or H) Pol
183±8 GHz, V (or H)
(166 and 183 GHz to have same resolution as 89 GHz)

Overlaps with the HF radiometer

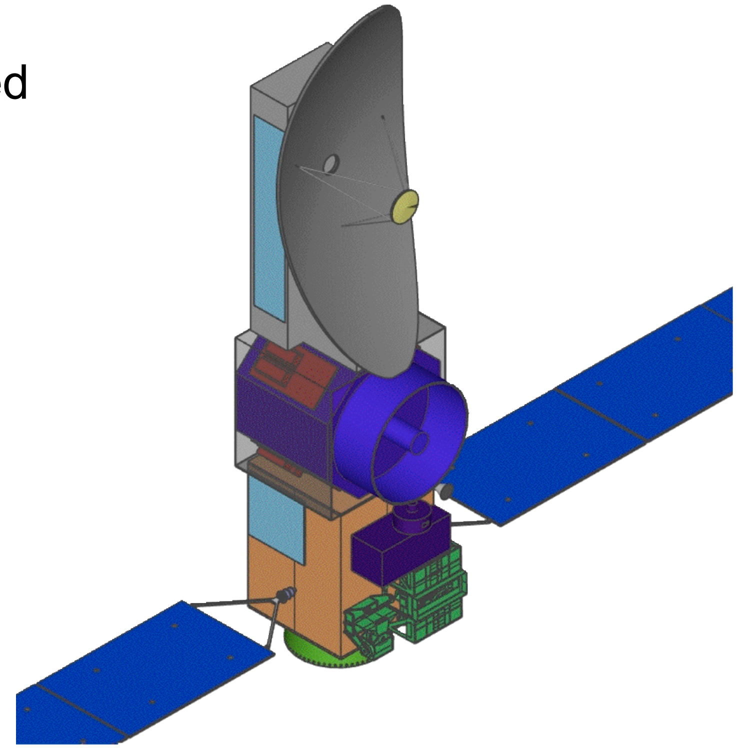
ACE/ACOB: Two Spacecraft Observing Geometry

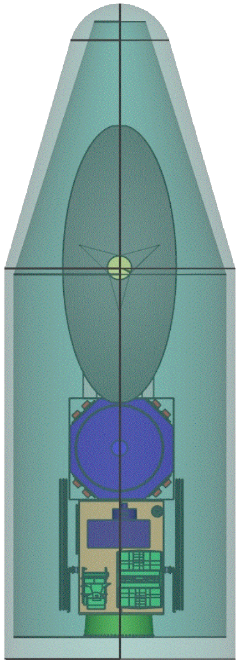




JPL's Single Platform ACE Mission

- This JPL version of ACE has four instruments
  - Cloud radar
  - MSPI
  - HSR Lidar
  - Ocean color radiometer
- Smaller payloads also considered
- Modified RSDO spacecraft bus
- 480 km altitude SSO





Next Steps with ACE as I see it

- Freilich wants to stick to the Academy mission but costs are much higher than Academy bogey
  - Nonetheless, I believe that a mission the meets the science needs (or more) will be considered – the science of ACE is at the very forefront of current societal needs.
- The white paper is in good shape and we should start from there rather than reinventing it.
- Let's try not to pre-select an instrument by torquing the requirements
- Community needs to develop a spectrum of ACE measurement options that meet the science needs yet allows us to peek at cost drivers
  - Changes to the NAS ACE payload will have to be carefully argued and justified based on science merit.
- Initial studies were just that – lots of options are still available. The final payload will be open competition.
- Let's not negotiate with ourselves on cost yet – we need to work together to get the science right and lets be open to good ideas and suggestions including configurations, international options